optoel 2013

VIII REUNIÓN ESPAÑOLA DE

Optoelectrónica

www.optoel2013.fgua.es

10-12
Julio de 2013

Alcalá de Henares
Madrid

LIBRO DE COMUNICACIONES

Grupo de Ingeniería Fotónica de la Universidad de Alcalá
GRIFO

Departamento de Electrónica
Universidad de Alcalá

Universidad de Alcalá

Publicado por:

Grupo de Ingeniería Fotónica
Departamento de Electrónica
Universidad de Alcalá

ISBN: 978-84-88754-21-9
Depósito legal: M-20974-2013

Wedged Analog Tunable Beam Steering Device based on Cholesteric Liquid Crystals

Eva OTON [1], Wiktor PIECEK [2], Przemysław MORAWIAK[2],
Morten A. GEDAY[1], Jose M. OTON[1]

1. CEMDATIC, ETSI Telecomunicación, Universidad Politécnica de Madrid, Av.Complutense 30, 28040 Madrid, Spain.
2. Laboratory of Crystals Physics and Technology, Department of New Technologies and Chemistry, Military University of Technology, ul. Kaliskiego 2, 00-908 Warsaw, Poland

Contact name: Eva Oton (eva.oton@upm.)

ABSTRACT:

In this work we propose a novel cholesteric liquid crystal beam steering device based on the Kerr effect. The first version of the device consists of two ITO coated glass plates, with intentionally prepared electrodes, assembled together with a thickness gradient between both sides of the device. One side of the cell has two substrates at direct contact; the other side has separated substrates to form the wedge. The cell was filled with a cholesteric liquid crystal. The liquid crystal material is an innovative mixture called 1892E with extremely low viscosity doped with a ZLI chiral nematogen.

The proposed beam steering device based on cholesteric liquid crystals has great potential for many photonic applications. Results describing the performance of the device and the properties of the selected liquid crystals are presented.

Key words: Liquid crystals, beam steering, free-space communications, optoelectronic adaptive element, cholesteric liquid crystals.

1.- Introduction

Liquid crystal devices are increasingly being used in non-display applications to manufacture low-cost, light-weight small devices that can be driven by low voltage electronics, and circumvent the use of movable parts or mechanical elements [1]. Non-display photonic devices based on liquid crystals can be loosely divided into phase modulation and amplitude modulation devices. Either kind acts over the state of polarization (SOP) of the impinging light [2]

Liquid crystal photonic devices may modulate the light temporally or spatially. In the first case time-dependent light modulation is obtained, whereas in the second case the result is a spatial light modulator (SLM) [3]. SLMs may be used in many applications, *e.g.* spatial filters, holograms, light-path compensators, tunable lenses or beam steerers.

Commercial and experimental spatial filters and holograms are chiefly based on active matrix microdisplays. Lenses and beam steerers on the other hand may be manufactured in a number of different approaches, including passive-driven and monopixel solutions. Moreover, their performance heavily depends on the conducting surfaces, alignment conditions and liquid crystal material, thus a large number of variables are available for the adaption of these devices to specific applications [4].

The aim of this work has been manufacturing, testing and measuring an improved liquid crystal device for laser beam steering, to be applied on different environments.

The device is a Wedged Analog Tunable beam steering (WAT BS). It is a graded index liquid crystal beam steering based on cholesteric liquid crystals manufactured in a wedged shaped configuration of the cell. The working principle of a liquid crystal based beam steering is as follows: given that the orientation of the liquid crystal indicatrix can be controlled by applying a voltage to the device, the change in the liquid crystal orientation results in a change of the effective refractive index n_{eff}. In this case, the effective refractive index of the liquid crystal is changed differently due to the thickness variation, obtaining a refractive index gradient. When a laser beam impinges on the device, the beam is deviated as the device works like a prism [5] [6] [7] [8].

2.- Wedged Analog Tunable Beam Steering Device

2.1.- Design

The WAT Beam Steering device has a fairly simple design. It consists of a liquid crystal cell, assembled in a wedged shaped configuration, *i.e.* manufactured with variable thickness (Figure 1).

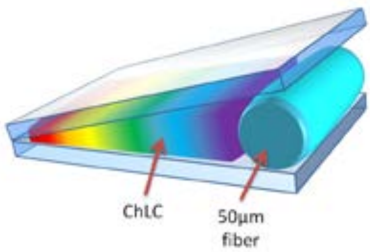

Fig. 1: WAT Beam Steering device design.

The cell is filled with a short pitch (0.4µm at room temperature) cholesteric liquid crystal mixture (1892E) developed at the Institute of Chemistry of the Military University of Technology, (WAT).

When a low voltage is applied to the electrodes an optical birefringence is induced:

$$\Delta n_{ind} = \lambda K E^2$$

where λ is the wavelength, K is the Kerr constant and E is the amplitude of the applied electric field.

Due to the variation of thickness a gradient of the liquid crystal shows upon switching and consequently a gradient of refractive index is observed. The wedge cell is actually a prism able to deflect a laser beam. When a voltage is applied the beam is deviated from its original position.

If the required deviation is not too large, short pitch cholesteric liquid crystals have several advantages over other liquid crystals: the response time is very short (in the sub-millisecond range) and the optical response is polarization independent; consequently the final set up becomes simpler. Moreover, they do not need an alignment layer, so the number of manufacturing steps is reduced.

2.2.- Manufacturing

To test the performance of the liquid crystal new mixture and the final beam steering effect several batches of wedge devices were manufactured. The device consists of two ITO coated glass plates with prepared electrodes. They are assembled with a thickness gradient between the device plates. One side of the cell has the two substrates at direct contact, while in the other side substrates are separated by a 50µm thick calibrated fiber to form the wedge (with an approximate angle of 0.10 arcsecond). The cholesteric liquid crystal mixture, 1892E, has an extremely low viscosity and is doped with a ZLI chiral nematogen. By doping with a selected ZLI chiral dopant it is possible to induce a broad temperature cholesteric phase with a short helical pitch at room temperature. The helical pitch induced by this compound is small enough for the structure of the compound to behave as optically isotropic for visible light with an effective refractive index being approximately $n_{eff}^2 = \frac{1}{3}(n_e^2 + 2n_o^2)$.

Upon applying an electric field the liquid crystal molecules align with the field, which means that an impinging beam parallel to the applied field will experience a smaller refractive index.

Different sets of wedge cells were manufactured and filled with different mixtures of cholesteric liquid crystals. Two different liquid crystals were tested as well: 1892E and TEC100. Three different amounts of added dopant were also tested: 3.5%, 5%, and 7.5%. The anisotropy reached by these liquid crystals is low (≈0.1); however the targeted deflection in our application was just 10 arcseconds, low enough for the selected cholesteric liquid crystals.

3.- Characterization and results

3.1.- Color shift patterns

The performance for all samples was checked using an optical microscope: a colored profile becomes visible by placing the sample between crossed polarizers. There is a color variation due to the thickness gradient in the device. When applying voltage to the cells, the graded switching profile of the liquid crystal develops and a color shift can be observed (Figure 2).The color shift corresponds to a change in the overall refractive index across the device. Due to the variation of electric field intensity a gradient of refractive indices is induced. A laser beam reaching the cell is deviated towards the direction of the thickness gradient.

One of the main problems of the already manufactured wedge cells is that they produce some aberrations in the incoming wavefront. The glass used for manufacturing cells was 0.7mm thick. This glass can be easily distorted under certain circumstances, so that the incoming wavefront will not find a perfectly flat but a curved surface, resulting in a distorted laser spot.

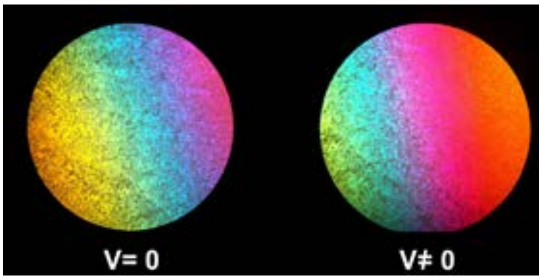

Fig. 2: Wedge cell with 1892E+5%ZLI mixture as seen between crossed polarizers under microscope: color shift observed when applying voltage.

Two possible solutions were proposed to correct this problem:

- Conforming the wavefront at the exit of the cell using a curved shaped prism to correct the wavefront distortion. This apparently simple solution is actually quite involved, since cells are not built identical to each other. It would be too laborious and time consuming to find the right shape for each single cell.
- Increasing glass thickness to avoid deformation of glass and hence wavefront distortion during the device driving. This was the chosen solution, as it is simpler and straightforward. A new set of thick wedge cells was manufactured: The chosen ITO coated glass thickness was 5mm (Figure 3).

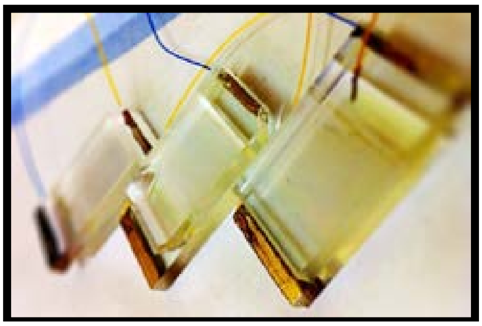

Fig. 3: Manufactured WAT Beam Steerer thick devices filled with 1892E+5%ZLI.

Nevertheless, working with 5mm thick glass substrates has some disadvantages; all devices and instruments in the clean room are optimized for thin glass, so all measurements and settings must be changed. Also, substrates are very heavy and could damage the instrumentation if no correct measures are taken. For example, a different adapter had to be used in the spin coater to ensure a tight vacuum. The new thick glass wedge cells were manufactured under the same conditions as the previous ones: using the same electrode design, same backplane design and maintaining the same wedge thickness variation of 0-50µm as well. Cells were then filled with 1892E+5%ZLI.

The performance of the thick glass wedge cells was checked under a microscope and between crossed polarizers. In outline, all cells showed an improved performance compared with the previous manufactured cells. Features that improved with the new wedge cells are:

- The behavior of the liquid crystal is more homogeneous: the devices exhibited fewer irregularities upon switching
- In thinner areas the devices showed less dispersion than in previous experiments.

3.2.- Deflection measurements

Deviation angles were measured for all devices. Spot deflection follows an approximately linear trend while increasing the voltage, as shown in Figure 4. Maximum achieved deflection angle for these devices was 0.018º (64 arcsec).

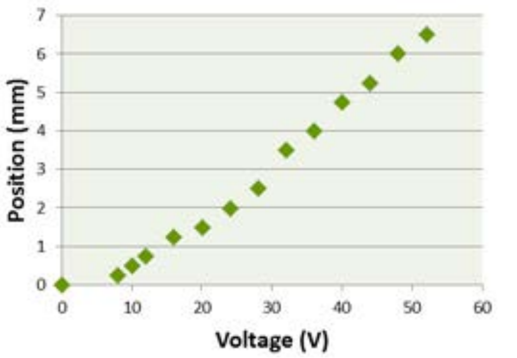

Fig. 4: Spot deviation vs. voltage in the WAT Beam Steerer device with 1892E+5%ZLI

Beam deviation measurements were always performed using a beam profiler. When applying voltage, a deviation in the direction of the thickness gradient is observed. This effect allows a control on the beam direction.

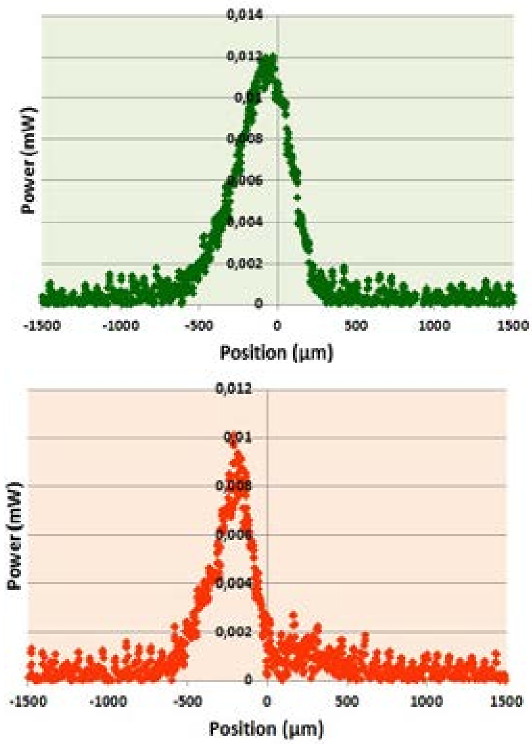

Fig. 5: Spatial power distribution of the beam profile in the Y axis when ΔV=0 (left) and ΔV=max (right).

The power distribution of the laser beam when applying voltage is shown in Figure 5: only the relevant axis is shown. Left plot corresponds to zero applied voltage (ΔV=0) in Y axis and right plot corresponds to maximum applied voltage (ΔV=max); so the deviation of the power can be observed. These measurements correspond to a device filled with 1892E+5%ZLI and thick glass.

Using the beam profiler software an approximation of the 2D spatial power distribution of the wavefront was obtained. Figure 6 shows the beam profile when no voltage is applied (left image) and when voltage gradient is maximum, (right image), obtaining the maximum deviation angle.

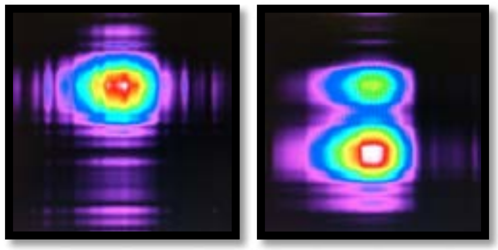

Fig. 6: Spatial power distribution of the beam profile in 2D. Applied voltage is ΔV=0 (left) and ΔV=max (right).

The laser beam gets deviated in one direction although a residual part of the light remains in the original position, most likely due to saturation effects.

3.3.- Response time

Response times were measured for the most relevant mixtures. The liquid crystal mixtures showing the best performance were chosen during the measurements in the laser setup.

Four mixtures were selected for the response times measurements, based on their behavior in the beam deflection. 1892E+3.5%ZLI and 1892E+7.5%ZLI were discarded as the mixtures were very dispersive. Average rise and fall times are shown in Table I.

Cholesteric liquid crystal mixtures employed for this application had very low response times. As previously mentioned, they are polarization independent, so no alignment layer is needed. The only drawback about this is that the liquid crystal is dispersive, and a fraction of the total impinging light was lost by scattering (≈15-25%).

Table. I. Response times for the mixtures in the WAT Beam Steerer

	t_{rise} (μs)	t_{fall} (μs)
1892E+5%ZLI	110	55
TEC100+3.5%ZLI	240	2500*
TEC100+5%ZLI	90	60
TEC100+7.5%ZLI	95	45

**The samples manufactured with this liquid crystal mixture showed very slow relaxation times in some cases, probably due to degradation of the material.*

4.- Conclusions

A 1D wedged analog tunable beam steering, based on cholesteric liquid crystals, has been demonstrated. The device is polarization-independent and remarkably fast.

The Kerr-effect-induced deviation of the WAT device displays a number of potential advantages, including polarization-independent switching in the submillisecond regime.

References

[1] E. HÄLLSTIG, J. STIGWALL, M. LINDGREN, L. SJOVIST,*"Laser beam steering and tracking using a liquid crystal spatial light modulator"* SPIE Proc. 5087, 13-23 (2003).

[2] Bruno FRACASSO, Jean Louis DE BOUGRENET DE LA TOCNAYE, Mushtaq RAZZAK, Chidi UCHE, "*Design and performance of a versatile holographic liquid-crystal wavelength-selective optical switch*" J. Lightwave Technol. 21 (10) 2405-2411 (2003).

[3] V. TKACHENKO, G. ABBATE, A. MARINO, F. VITA, M. GIOCONDO, A. MAZZULLA, L. De STEFANO, *"High accuracy optical characterization of anisotropic liquids by merging standard techniques"* Appl. Phys. Lett. 89, 221110 (2006).

[4] Steve SERATI, Jay STOCKLEY, "*Advances in liquid crystal based devices for wavefront control and beamsteering*" SPIE Proc. 5894, 180-192 (2005).

[5] Eva OTÓN, Wiktor PIECEK, Przemysław MORAWIAK, Dorota ZIOBRO, Roman DABROWSKI, Zbigniew RASZEWSKI. Leszek JAROSZEWICZ, *"Kerr Effect in cholesteric liquid crystals for beam steering devices"* 13th International Symposium on Colloidal and Molecular Electrooptics (Ghent, 2012).

[6] J. YAN, Y. LI, S.T. WU, *"High-efficiency and fast-response tunable phase grating using a blue phase liquid crystal*" Opt. Lett. 36 (8) 1404-1406 (2011).

[7] L. RAO, Z. GE, S. GAUZA, K.M. CHEN, S.T. WU, *"Emerging liquid crystal displays based on the Kerr effect"* Mol. Cryst. Liq. Cryst. 527, 186-198 (2010).

[8] J. YAN, H.C. CHENG, S. GAUZA, Y. LI, M. JIAO, L. RAO, S.T. WU, *"Extended Kerr effect of polymer-stabilized blue-phase liquid crystals"* Appl. Phys. Lett. 96, 071105 (2010).

Lugar de celebración:

Universidad de Alcalá
Alcalá de Henares (Madrid)

Secretaría Técnica de la Reunión:

Fundación General de la Universidad de Alcalá
C/ Imagen, 1 - 3
28801 Alcalá de Henares. Madrid
Tel.: 91 879 74 30
Fax: 91 879 74 55
E-mail: optoel2013@fgua.es

www.optoel2013.fgua.es

Organizado por:

GRIFO – Grupo de Ingeniería Fotónica de la Universidad de Alcalá
Departamento de Electrónica – Universidad de Alcalá
Universidad de Alcalá

Con la colaboración de:

SEDOPTICA – Sociedad Española de Óptica
Comité de Optoelectrónica – Sociedad Española de óptica
Alcalá de Henares Ayuntamiento – www.ayto-alcaladehenares.es – www.alcalacultura.es
OMCA – Oficina Municipal de Congresos de Alcalá de Henares
FACTOTEM
La Suma de Todos – Comunidad de Madrid – www.madrid.org
Unión Europea – Fondos Estructurales – Invertimos en su futuro